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# "INDOOR AIR QUALITY INSIDE PREMISES WHERE NATURAL GAS APPLIANCES ARE OPERATING"

ABSTRACT. This paper deals with the correlation existing between the combustion of natural gas by appliances operating in the domestic environment, and indoor air quality found in these same environments, to the following effect.
Certain considerations are developed relating to the most widespread appliances, particulary to new types of burners able to reduce the amount of pollution produced by combustion.
The process of natural gas combustion is analysed, under conditions of both regular and anomalous operation of the burners.
In conclusion, research initiatives are examined for the development of devices to reduce $NO_x$, and for the prevention of the reflux of products created by combustion into the environment.

## 1. INTRODUCTION

In the past three decades, a significant effort has been placed by the research and professional community in developing technologies and regulations aimed at protecting the quality of outdoor air.

In recent years only, it has been argued that even higher risks for human health may derive from the exposure to indoor air pollution, for two basic reasons: firstly because in developed countries most people spend the greater part of their lives in confined spaces, secondly because pollutants may be present in indoor air at levels which are higher than outdoors and hazardous to humans.

The gas industry - which has played an important role in the fight against atmospheric pollution, by promoting the diffusion of a "cleaner" energy source - is deeply concerned about the Indoor Air Quality (IAQ) issue.

There are several reasons which justify an active involvement of the gas industry in research on IAQ. One reason is the fact that combustion equipments (no matter what fuel they use) are a potential source of indoor pollution. Compared to other sources of indoor pollution, which are virtually impossible to eliminate and often even to reduce, the impact of gas appliances on indoor air can be controlled by proper design, installation and maintenance.

A second important aspect is the interplay between IAQ, safety and energy efficiency. It is well known that one of the causes of poor indoor air quality is insufficient ventilation, a consequence of "unwise" energy saving policies; but poorly ventilated spaces, in turns, can also be unsafe, if they host combustion equipment; safety and higher IAQ are therefore linked goals, which must be pursed by technological innovation, better design and more detailed regulations.

Finally, there are interesting opportunities for development in gas combustion technology, leading to higher energy efficiency and lower pollutants emission, applicable not only to large industrial plants, but also to small-scale residential installations.

## 2. THE COMBUSTION OF GAS AND IAQ

Combustion appliances for cooking, service hot water production, or space heating are normally present in Italian dwellings. Such appliances, which are mostly fired with natural gas or LPG, have an impact on IAQ whenever flue gases are released indoors.

Combustion of natural gas originates, under stoichiometric condition, carbon dioxide and water vapour.

In addition to such components, other substances are generated in real combustion processes which need consideration: Carbon Monoxide (CO) and Nitrogen Oxides ($NO_x$) are the most significant indoor pollutants which may form in the combustion of natural gas.

The risks that may be attributed to exposure, even for limited times, to CO concentrations in indoor air exceeding a few hundreds ppm are well known. NO itself has a negligible sanitary impact, but constitutes the first step in the formation of photochemical smog, a complex mixture of substances, including ozone and nitrogen dioxide, which are hazardous to human health.

The formation of both CO and NO are closely linked to the combustion conditions. A high concentration of CO in flue gases is due to incomplete combustion, which takes place if the supply of oxygen to the flame region is low campared to the mass of gas to be burned. In domestic gas appliances, such phenomenon may be due to incorrect gas supply or, more frequently, to anomalies in the supply of combustion air. The link between CO formation and $O_2$ concentration in air is clear: if the latter drops to about 19%, the rate of formation of CO raises dramatically.

The most usual causes of air supply anomalies are the following: a poorly designed gas exhaust system or an insufficient supply of combustion air, due either to the underdesize or even to the absence of purpose-provided openings.

The installation of gas appliances in living spaces and the combustion air supply characteristics are specified in Italy by law, as discussed in section 3.

The formation of NO is mostly influenced by the combustion temperature, the excess of air, and the residence time of flue gases in the high-temperature flame region. All such parameters may be controlled, at least in theory, by proper design and management of the combustion process.

As it will be discussed in section 4, Italgas has been involved in recent years in several research program related to IAQ. The main line of research is concerned with innovative combustion technologies, aimed at $NO_x$ reduction in gas flames (see section 4.1). Such technologies have a significant impact, both in reducing atmospheric pollution and improving IAQ. In addition to this research area - which is carried out in Italgas's laboratories - a new program on IAQ has been recently started (see section 4.2.).

## 3. ITALIAN STANDARDS ON THE VENTILATION OF ROOMS WHERE GAS EQUIPMENTS ARE OPERATING

There is, at present, no specific set of regulations in Italy regarding the quality of air in domestic environments. Nevertheless, the UNI-CIG regulations, enacted at the beginning of the seventies, though indirectly are the first set of regulations regarding the quality of air in domestic environments where gas equipment is operating.

These regulations concern problems regarding the safety of gas equipment and, in particular, the discharge of combustion products and the replacement of combustion air in premises in which gas equipment is installed.

The following are the main points of these regulations:

a) gas equipment for the heating of premises and the production of domestic hot water (with the exception of small instant water heaters) must by law be connected to a flue with outlet into the open air;

b) cooking equipment (rings, cookers) must discharge combustion products into special hoods connected to flues or leading directly outside. It has been demonstrated experimentally, though, that even where this regulation is ignored, as long as the regulations regarding ventilation of premises are respected, exposure to nitrogen oxides is negligeable, and in any case below the levels indicated by literature as the threshold of risk. This is due to the modest output of the equipment installed (in the order of 10 ÷ 12 kW), the short time for which it is employed and its occasional use (at most 1-2 hours twice a day);

c) the regulations for the ventilation of premises in which gas equipment is operating, require permanent ventilation openings of at least 6 $cm^2$ for every 1.16 kW installed capacity, with minimum free ventilation area of 100 $cm^2$. These openings ensure that the equipment operates regularly and correctly, combustion being optimal (with negligeable production of carbon monoxide), and at the same time they facilitate the ventilation of the premises with the consequent dilution and elimination of other pollutants, such as water vapour and carbon dioxide, deriving from domestic activities.

In conclusion, the utilization of gaseous fuels, in accordance with the regulations cited above, does not compromise the quality of the indoor air in closed premises.

## 4. THE ROLE OF THE GAS INDUSTRY IN IAQ RESEARCH: ITALGAS'S EXPERIENCE

Gas companies have always paid attention to the problem of environmental pollution, and in particular to that of the indoor environment. Italgas, for example, has been involved for a considerable time in sectors of particular interest:

- in supporting research and technological development of low environmental impact burners;
- in supporting the introduction of regulations concerning gas equipment and clean combustion;
- carrying out studies on the quality of air.

### 4.1. Research into new conception burners and development of relevant technology

Italgas's activity in this sector is aimed in particular at verifying the environmental performance, as well as the energy performance of burners which limit the production of nitrogen oxides ($NO_x$).

This greater interest for $NO_x$ than for other pollutants is a consequence of the physical and chemical characteristics of natural gas;

- physical, because with natural gas it is possible to create homogeneous fuel-air mixtures, thus reducing the quantity of unburnt products;
- chemical, because in the composition of natural gas, certain pollutants are absent (sulphur compounds) and thus the combustion products are particularly clean. Furthermore, although the stoichiometric combustion process produces water and carbon dioxide, the need to operate in an excess of air in order to complete and speed up the combustion reaction causes nitrogen oxides to be produced.

4.1.1. The formation of the nitrogen oxides and some measures to reduce their emission. Various factors influence the formation of nitrogen oxides during the combustion process: flame temperature, excess of air, reaction times, as well as the type of reaction adopted.

The scientific literature and tests carried out show that, because of its physical and chemical characteristics, gas is the fuel which, conditions being equal, produces the smallest quantity of nitrogen oxides.

TABLE 1 - Estimate of the emission, in tons, of the main atmospheric pollutants in Italy in 1984.

| | Coal | Natural gas | Petrol | Diesel oil | Fuel oil | Tot. |
|---|---|---|---|---|---|---|
| Sulphur oxides | 179,000 | 292 | 6,400 | 240,000 | 1,740,000 | 2,165 |
| Nitrogen oxides | 109,000 | 107,000 | 498,000 | 497,000 | 220,000 | 1,431 |
| Suspended particles | 9,050 | 1,440 | 21,300 | 214,000 | 118,000 | 3,637 |
| Carbon oxides | 10,000 | 19,200 | 4470,000 | 578,000 | 17,900 | 5,095 |
| Volatile Organic compounds | 1,910 | 7,060 | 379,000 | 253,000 | 4,030 | 6,400 |

As can be seen from Table 1 [2], emissions of $NO_x$ from the combustion of natural gas for domestic, manufacturing and commercial use in Italy are much less conspicuous than those derived from other fuels, in particular from solid and liquid fuels.

TABLE 2 - Division of the emission in tons of the main atmospheric pollutants in Italy in 1986, by type of utilization of the fuel.

| | Agric. fish. | Transport | Ind. | Resid. comm. | Electr. produc. | Tot. |
|---|---|---|---|---|---|---|
| Sulphur oxides | 22,000 | 84,000 | 616,000 | 153,000 | 1,199,000 | 20740 |
| Nitrogen oxides | 74,000 | 809,000 | 189,000 | 69,000 | 428,000 | 15690 |
| Suspended particles | 28,000 | 231,000 | 49,000 | 48,000 | 56,000 | 4120 |
| Carbon oxides | 148,000 | 5048,000 | 87,000 | 261,000 | 26,000 | 55700 |
| Volatile organic compounds | 41,000 | 668,000 | 8,000 | 44,000 | 7,000 | 76800 |

From Table 2 [3], which gives the emission from combustion processes of the major atmospheric pollutants in Italy in 1986, analysed by sector according to the use of the fuel, it emerges that the sector with the highest production of nitrogen oxides is transport by road, followed by the production of electricity.

With regard to CO, petrol and diesel (Table 1) and thus the transport sector (Table 2) are the fuel and sector of utilization, respectively, which are most polluting.

As already mentioned, the theory states that the formation of nitrogen oxides depends predominantly on the reaction temperature, and to a lesser extent on the partial pressure of the comburent oxygen.

Some measures make it possible to reduce the emission of NO, in particular:

- the effective combustion temperature should be kept as low as possible;
- the partial pressure of oxygen should be reduced;
- the air index should be kept as low as possible: Fig. 1 gives the emissions of nitrogen oxides and carbon monoxide as a function of the air index for a forced-air gas burner. The reduction of the excess of air is a delicate operation because, as can be seen from the diagram (Fig. 1), a reduction of the air index corresponds both to a reduction of nitrogen oxides, and at the same time to an increase in the production of carbon monoxide;
- the time which the gas remains in the zone above 1300°C should be reduced.

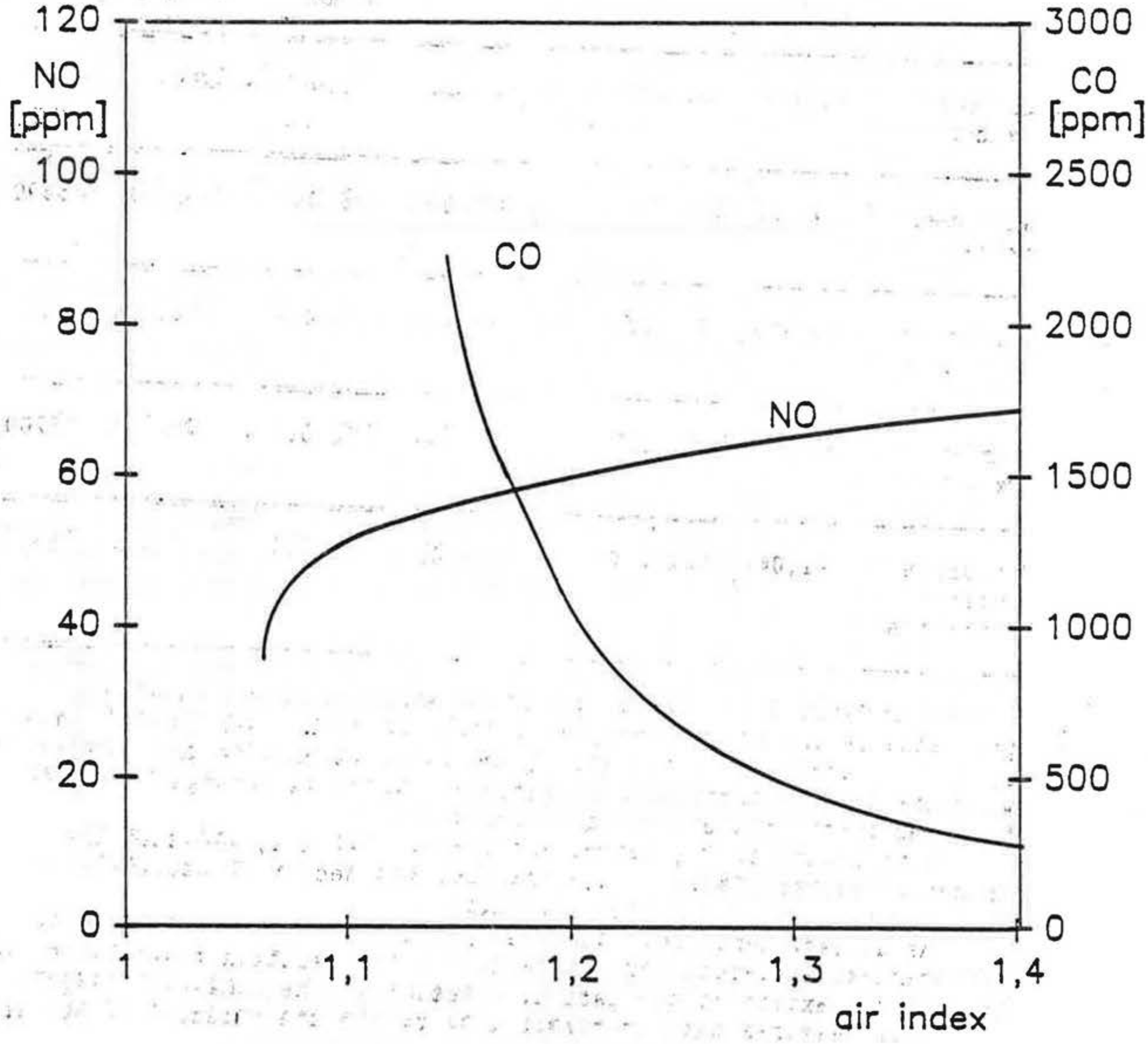


FIGURE 1 - NO and CO emission from a forced-air gas burner

4.1.2. Review of the types of burners. The following types of burners limit the production of nitrogen oxides.

a) Burners with complete pre-mixing of fuel.

Burners with complete pre-mixing of fuel and air are at present believed to be most effective in limiting the production of nitrogen oxides. With this type of burner, with increased mixing of fuel and air, it is possible to avoid or limit zones of high temperature. These burners also possess the positive characteristic of permitting combustion with smaller excesses of air, without excessive increase in the emission of carbon monoxide.

b) Catalytic burners.

The aim of these burners is to reduce the temperature of the flame by using suitable catalyzers to allow the combustion process to develop at lower temperatures.

c) Burners with insert (ceramic or metal).

In these burners, the temperature reduction in the combustion zone comes about through a suitably-placed insert which dissipates part of the heat of the flame into the combustion chamber. Materials are used which are resistant to high temperatures; these can be ceramic or metals.

d) Ceramic burners.

The operating principle, which is common to practically all models, can briefly be described as follows. Gas fuel and air, thoroughly pre-mixed, pass through a porous ceramic burner; a pilot light starts combustion on the surface of the burner; combustion then becomes selfsustaining, causing the outer surface of the ceramic support to become incandescent.

Another interesting characteristic is the size and shape of the flame, which remains small: just a few millimetres. The combustion temperature is also kept within limits (approximately 1000 °C).

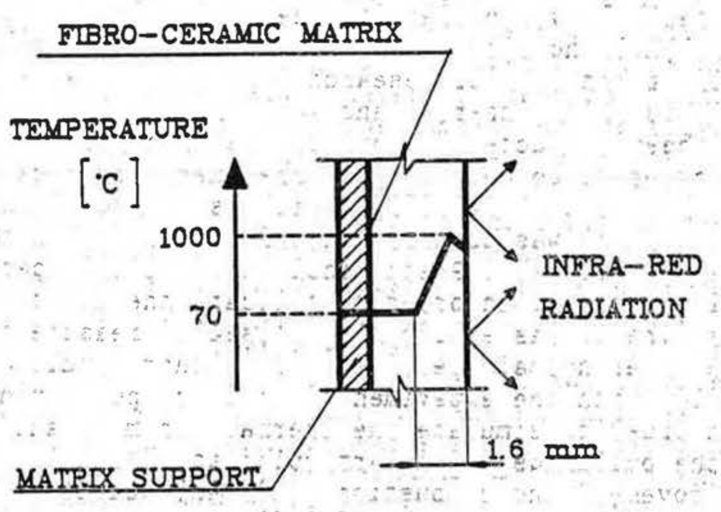


FIGURE 2 - Diagram of the temperature within the fibro-ceramic burner

Figure 2 is a diagram of the temperatures within the fibro-ceramic support. On the surface, temperatures of 850 to 1100 °C are reached; this low temperature keeps emissions of $NO_x$ in the order of 10 - 20 ppm.

e) Perforated matrix burners.

This type of burner consists of a support for combustion made of a perforated ceramic material. In this case, the pre-mixed fuel and air pass through the perforations in the support and produce an external combustion with a free flame, which is very close to the support and exchanges radiant heat with this.

Operating temperatures are of the order of 900 °C, and emissions of nitrogen oxides are below 20 ppm.

Some problems with this type of burner are:

- possible flash-back during operation in the radiant field;
- difficulty of obtaining correct operation below 20% excess of air;
- vulnerability to thermal shock due to the considerable mass of ceramic support.

f) Burners with metallic mesh.

In these burners, a metallic mesh or a perforated steel sheet substitutes the ceramic matrix as a support for combustion. The mesh is manufactured from stainless steel or Inconel, which have similar performances to those of the ceramic support. In order to avoid overheating of the radiating screen, these burners must operate with an excess of air between 30 and 50%, but despite this the emission of nitrogen oxides remains below 20 ppm.

## 4.2. Experimental research program on IAQ

An experimental research program, jointly conducted by Italgas and Politecnico di Torino, is presently under way.

Two identical, instrumented single-family houses have been recently completed by Italgas. Such dwellings have been constructed according to a design and technology representing the current building practice, and complying with existing regulations on safety and energy conservation

During the first year of research (September 1990 - August 1991) a thorough analysis of the thermal and fluidynamic behaviour of the two buildings has been conducted. A computerized monitoring system was installed in order to collect data on the energy balance of the buildings (weather data, indoor temperatures, energy consumption). Infrared thermography was used to identify anomalies in the building envelope (thermal bridges). Pressurization tests were performed using calibrated blower doors, in order to evaluate the air thightness of the two dwellings. Tracer gas equipment was used to measure the actual air exchange rate under normal operating and weather conditions.

In parallel with the experimental work, computer models were developed, in order to simulate the thermal dynamics and the air flow patterns in the buildings, with particular attention to the interplay beetween air movement and combustion equipment operation.

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